A step forward in running-related injuries

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General introduction

RUNNING FOR HEALTH

Running has become a popular activity among men and women of all ages. About 50 million Europeans run as a way to remain healthy [1]. Running has many health benefits that include improved cardiovascular and mental health, weight loss, and physical fitness. Running is also an important part of the daily training practice of many athletes who want to enhance their performance in a specific sport. Another explanation for the popularity of running is that it requires little equipment and can be done everywhere: all you need is a pair of shoes. So for many people who strive to have a healthy and fit body, running is their first activity of choice.

EPIDEMIOLOGY OF RUNNING RELATED-INJURIES

Running-related injuries frequently occur among all types of running/runners and include various types of overuse and acute injuries [2,3]. The most prevalent RRIs are patellofemoral pain syndrome (prevalence 7.4%–15.6%), medial tibial stress syndrome (prevalence 9.5%), and lower limb tendinopathies, including iliotibial band syndrome (prevalence 10.5%), Achilles tendinopathy (prevalence 2.0%–18.5%), plantar fasciitis (prevalence 5.2% –17.5%), and patellar tendinopathy (prevalence 12.5%) [4]. A major concern of running-related injuries is that their incidence is on the rise. Between 2.5 and 33 injuries for every 1000 hours of running have been reported in recreational and novice runners, leading to an injury incidence between 7.7 and 17.7 [5]. A time-loss injury proportion for various populations of runners ranges from 3.2% to 84.9%, depending on the injury definition used [3].

RRIs may cause runners to discontinue running; injuries are the main reason for about 30% of those who ceased in the middle of a running program [6]. RRIs also impose high medical costs [7,8] and have the potential to negatively influence runners' lifestyle and physical health [9]. Runners who sustain an injury will have difficulty maintaining a healthy and physically active lifestyle [10].

INJURY PREVENTION MODELS

Several injury prevention models have been introduced [11–16], with more recent models trying to improve the previous ones. The final goal of all models is to prevent sports injuries using information on potential risk factors associated with the occurrence of injuries. The first injury prevention model that includes four fundamental steps (identifying incidence and severity, ascertaining the etiological risk factors, introducing preventative measures, and testing preventive measures in RCT) was described by van Mechelen in 1992 [11]. Finch et al., via the Translating Research into Injury Prevention Practice (TRIPP) framework, extended the original van Mechelen injury prevention model by introducing two more steps related to implementation and integration of interventions [13]. These models acknowledged the multifactorial nature of sports-related injuries. Most studies conducted on etiology of running-related injuries focus on isolated risk factors though. The multifactorial nature of sports-related injuries emerges from the combination of and interaction between several risk factors. These interactions are represented by an injury prevention model introduced by Bittencourt et al. (2016) [15]. This conceptual model of injury prediction, as illustrated in Figure 1, shows how several risk factors with different weights (darker circles show more interaction and greater influence on injury pattern) interact and contribute toward developing an injury. The model indeed elucidates the complexity and multifactorial nature of sports injuries. Accordingly, several risk factors interactively contribute to the development of an RRI.

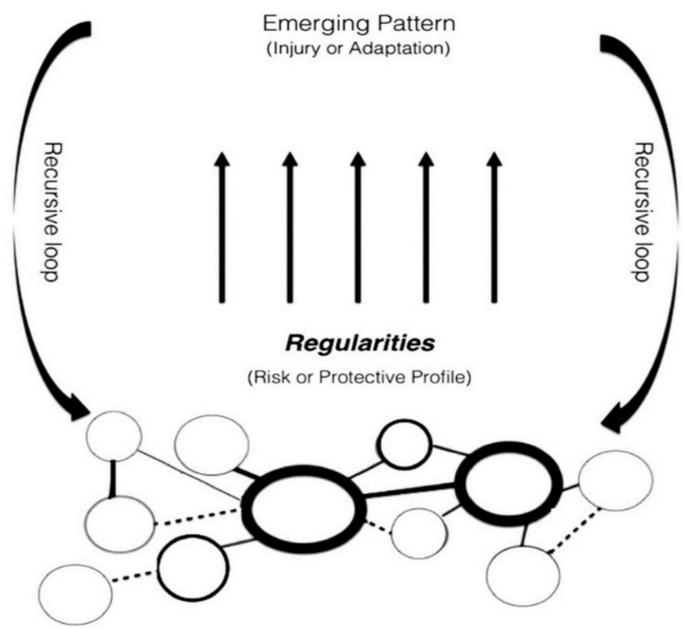

Figure 1. Complex model for sports injury represented by Bittencourt et al. (2016) [15]. The circles at the bottom comprise the web of determinants, which is composed of contributing variables with different weights. Variables circled by darker lines have more interactions than variables circled by lighter lines and exert a greater influence on the outcome. Dotted lines represent a weak interaction and thick lines represent a strong interaction between variables. Arrows indicate the association between the observable regularities, which captures the risk/protective profile, and the emerging outcome (figure adapted from [15]).

RISK FACTORS ASSOCIATED WITH RUNNING-RELATED INJURIES

RRIs thus have a complex and multifactorial nature, which implies they are reliant upon interactions of many risk factors. Risk factors possibly associated with RRIs can be classified into two broad categories: intrinsic and extrinsic. Intrinsic risk factors include personal characteristics such as age, height, weight, lifestyle, genetics, mental aspects, previous injury(ies), and biomechanical factors. Extrinsic risk factors include running-related factors such as running distance, running frequency, running duration, and running speed, running equipment (shoes, insoles), running surface, environment, and coaching. Identifying and addressing modifiable risk factors associated with an injury is one of the important elements of preventive strategies. Especially modifiable risk factors such as running-related risk factors, BMI and biomechanical risk factors have been widely addressed in RRI studies, as these factors are under the control of runners, coaches, clinicians, and physiotherapists, and have the potential to be modified.

Figure 2 is an attempt to illustrate the web of risk factors for running-related injuries based on the model depicted above. The risk factors and their joint interactions were determined according to the information obtained from literature on running-related injuries. Previous injuries [2], training-related factors [17], and biomechanical factors [18–20] are the main elements of the web of risk factors for running-related injuries. These factors play an important role in most of the interactions, passively or actively. For example, the biomechanical factors are influenced by training load, sex, foot strike, running surface, BMI, surface, and shoes. Likewise, psychological factors influence training-related factors.

So far many risk factors have been reported which predispose runners to injury, yet there are many factors whose associations with running-related injuries are still unknown and whose exact role in the development of RRIs has to be elucidated. These factors are specified with question marks in Figure 2 and some of them will be investigated in this thesis.

BIOMECHANICAL RISK FACTORS FOR RUNNING-RELATED INJURIES

Biomechanical risk factors are considered to play an important role in the etiology of RRI and are often modifiable [18,20–24]. Biomechanical factors can be classified into three categories: kinetic, kinematic, and spatiotemporal. These categories have been widely investigated in runners using two-dimensional or three-dimensional motion analysis systems to distinguish the biomechanical differences between runners with and without RRIs. Three-dimensional motion analysis systems are reliable and validated methods for gait analysis. These systems are commonly used for research but barely used in clinical practice. 3D systems are expensive, procedures are impractical and time-consuming, and to operate these systems expertise, knowledge, and experience are needed. Hence 2D motion analysis systems are widely used for gait analysis in clinical settings because they are cheap and portable and do not require in-depth knowledge to be operated. Knowledge about their reliability and validity is lacking though. A 2D gait analysis tool that is reliable and valid could aid clinicians and researchers.

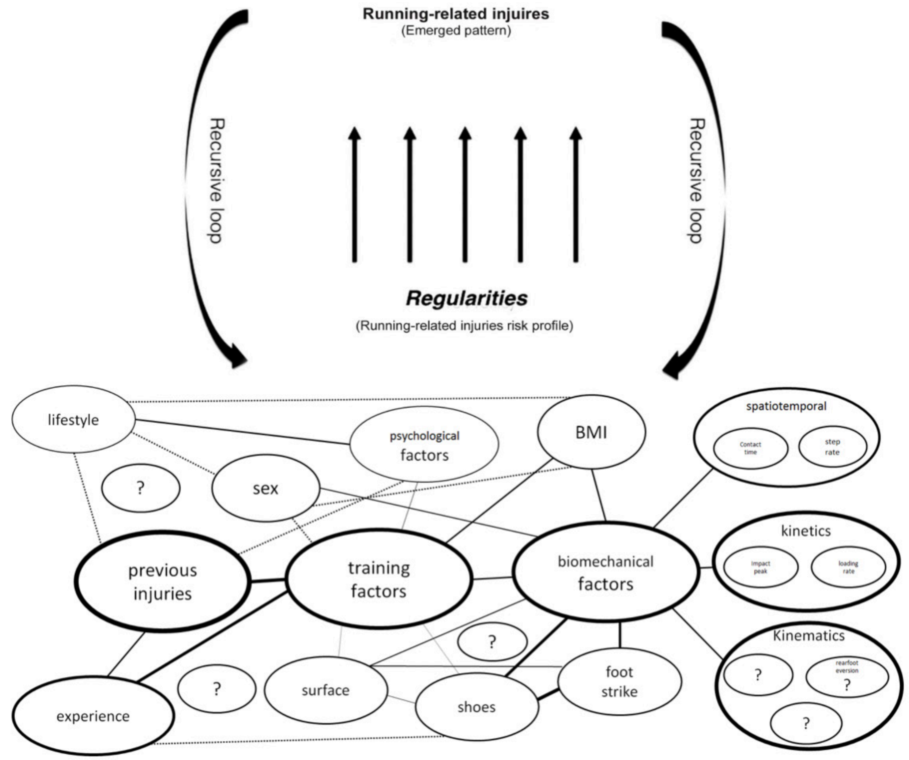

Figure 2. Web of risk factors for running-related injuries (information about risk factors obtained from literature). The circles at the bottom comprise the web of determinants, which is composed of contributing variables with different weights. Variables circled by darker lines have more interactions than variables circled by lighter lines and exert a greater influence on the outcome. Dotted lines represent a weak interaction and thick lines represent a strong interaction between variables. Arrows indicate the association between the observable regularities, which captures the risk/protective profile, and the emerging outcome.

Several kinematic factors have been suggested to play a role in the development of running-related injuries. The kinematic factors most frequently investigated for such injuries include rearfoot kinematics [25–33], hip adduction [33–36], hip internal rotation [37–40], and knee internal rotation [32,33,36,41–43]. Normal kinematics allow the body to better attenuate and absorb impact by distributing it over soft tissue. By contrast, besides disturbing the process of shock attenuation abnormal kinematics may affect the adjacent joint kinematics. This implies kinematic chains. Kinematic chains are formed to express the association between body segments and joints during locomotion. In fact, in kinematic chains adjacent segments should collaborate optimally to move the body in the proper direction. Running consists of both close and open kinematic chains, related to the phase of movement. During the stance phase of running the kinematic chain is closed, meaning that the movements of proximal segments depend on the movements provided by distal segments [44]. Alterations in joint angles therefore influence other joint angles, especially if this alteration is started in the foot as lowest segment.

FOOT STRUCTURE

The foot as the lowest segment of the body plays an important role in the kinematic chain during locomotion. Any changes in the movement of the foot can affect segment couplings, thereby influencing the movement patterns of the body. The foot is commonly described as three separate anatomical segments: rearfoot, midfoot, and forefoot. The rearfoot includes calcaneus and talus; the midfoot includes five bones: navicular, cuboid, and three cuneiforms; the forefoot includes the metatarsals and phalanges [45]. Depending on the phase of gait, the foot can act as a rigid structure for weight bearing. The foot can also act as a flexible structure to adapt to uneven surfaces. During running, proper coordination among foot segments is required in order to properly aid with shock absorption, provide balance, support body weight, and transfer ground reaction forces.

SUBTALAR PRONATION (REARFOOT EVERSION)

The rearfoot includes the subtalar or talocalcaneal joint, which is formed between the talus and the calcaneus. The subtalar joint allows pronation and supination of the foot. The subtalar joint axis is not aligned with the ankle joint axis, which makes its 3D planar movement calculation difficult [46]. The rotation axis of the subtalar joint is oblique to both the transverse and sagittal planes. It is inclined 16° medially from the longitudinal axis of the foot and 42° superiorly and anteriorly from the transverse plane in the sagittal plane (Figure 1) [46–48]. Subtalar pronation consists of three motions of the foot: rearfoot eversion, ankle dorsiflexion, and forefoot abduction [49]. The main function of subtalar pronation is to facilitate the rotational movements of the lower limbs during the stance phase [50]. Functionally, subtalar pronation itself is a necessary movement during locomotion, as it helps the bodyweight to transfer throughout the foot during the stance phase of gait [51].

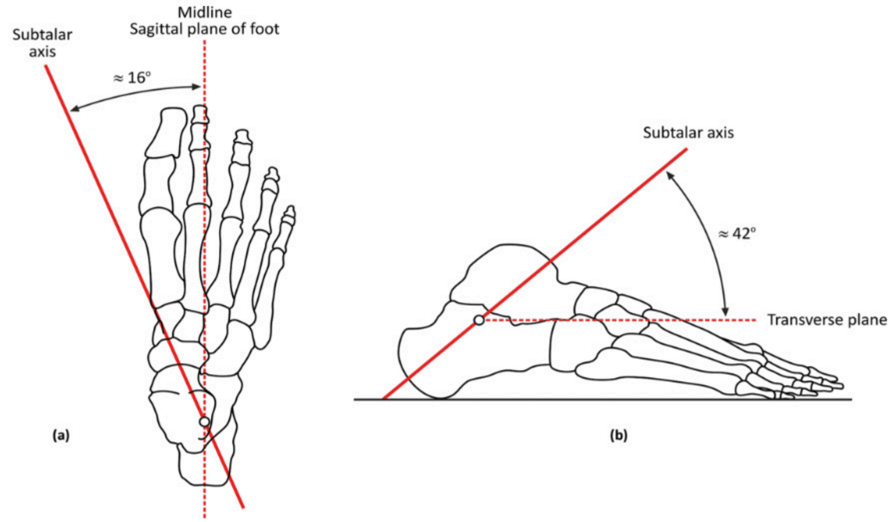

Figure 1. Axis of the subtalar joint. It shows: (a) 16° oblique deviation from the foot midline in the transverse plane subtalar joint axis and (b) 42° horizontal deviation in the sagittal plane of the foot (figure adapted from [52].

ATYPICAL PRONATION AND ITS EFFECT ON THE BIOMECHANICS OF LOWER LIMB

Subtalar pronation is considered atypical if the following two conditions occur during gait: when pronation is greater than normal (excessive pronation) and when the subtalar joint is still in pronation during the stance phase of gait while it should be supinated. Excessive subtalar pronation causes the foot to be hypermobile and results in subsequently ineffective and insufficient actions of muscles and ligaments. This leads to soft-tissue breakdown, impeding the foot's necessary function during gait.

In normal running with a heel landing the rearfoot is the first body segment to impact the ground, so imperfect rearfoot biomechanics disrupt the entire lower limb kinematic chain, imposing extra forces on the proximal structures that may lead to injuries [53]. Atypical subtalar pronation obstructs the normal rhythmic time of pronation during gait by changing the duration of pronation [54]. This can produce an unstable base during locomotion, thereby increasing the chances of injury. The movement coupling in the lower limb is potentially an associated factor in the development of lower limb injuries [55–58]. One of the important lower limb movement couplings is rearfoot eversion/ tibia internal rotation, which occurs due to the oblique shape of the subtalar joint [59]. During the first half of the stance phase foot pronation is coupled by internal tibial rotation, knee flexion, and hip internal rotation. On the other hand, foot supination is accompanied by external tibial rotation, knee extension, and hip external rotation mainly occurring in the late stance phase [60] (propulsive period) [59,61–63].

Atypical subtalar pronation such as hyperpronation causes excessive internal rotation of tibia, followed by a compensatory internal rotation of the femur (Figure 2) [60]. In fact, excessive pronation leads to mistiming of lower limb movement couplings. This will increase lateral tracking of the patella. The higher the internal rotation of tibia, the higher the force on the knee, laterally displacing the patella and subsequently increasing the Q-angle (the angle formed between the line from the center of the patella (kneecap) to the anterior superior iliac spine of the pelvis and the line from the patella to the tibial tubercle). This may cause the patella to become painful due to patellar maltracking on the femoral condyle [64].

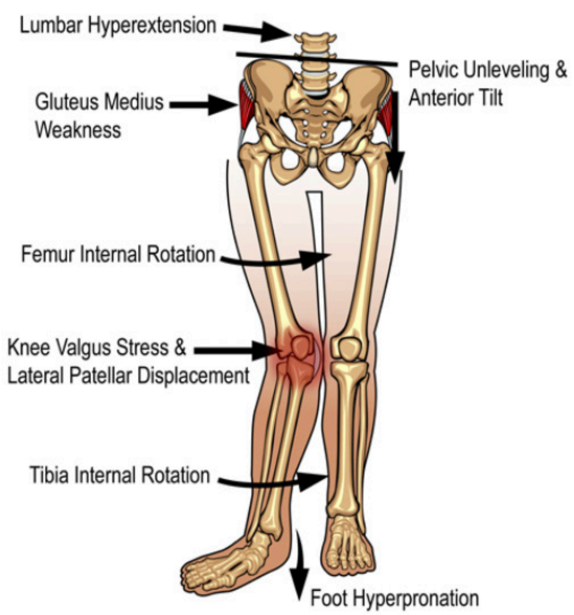

Figure 2. Hyperpronation and its influence on the kinematic chain (figure adapted from [65])

ATYPICAL PRONATION AND ITS ASSOCIATION WITH OVERUSE INJURIES

Atypical subtalar pronation by influencing foot and lower limb structural function may cause lower limb overload and consequently overuse injuries. Subtalar pronation is considered one of the main factors causing such overload [53]. Although current evidence confirms the potential effect of subtalar pronation on lower limb biomechanics [66], contradictory evidence in the literature regarding the contribution of subtalar pronation (rearfoot eversion) to running-related injuries hampers drawing any direct conclusion in this respect. Excessive subtalar pronation is associated with increased lower limb joint moments and forces. Individuals with greater peak rearfoot eversion and longer duration of rearfoot eversion are more prone to develop medial tibial stress syndrome during both walking and running; with a 1% increase in rearfoot eversion the odds of developing medial tibial stress syndrome rises 1.38-fold during walking and running [67–69]. Since rearfoot eversion is highly associated with hip adduction and hip internal rotation, it may also be considered a contributing factor for patellofemoral pain syndrome, with the same injury mechanism described in the previous paragraph [56,70–72]. By contrast, several studies report a lacking association between rearfoot eversion with various types of running-related injuries such as Achilles tendinopathy [27,31], patellofemoral pain syndrome [73], and iliotibial band syndrome [32,36].

The calf muscles are considered the most powerful subtalar supinator because of the insertion of the Achilles tendon located in the medial side of the calcaneus [74]. When excessive subtalar pronation occurs repetitively, the Achilles tendon may undergo overuse degeneration and inflammation. Subtalar pronation leads to a whipping action on the Achilles tendon. The whipping action can cause microtears in the Achilles tendon when it exceeds the normal range [75]. The role of foot pronation on Achilles tendon blood flow in runners shows that a greater rearfoot eversion lowers Achilles tendon blood flow after a 10-min run, suggesting the methods to avoid excessive foot pronation are useful in preventing and managing Achilles tendinopathy [76].

The plantar aponeurosis is the major ligament in the plantar side of the foot supporting the medial longitudinal arch [77]. The plantar fascia is the location of one of the most common foot injuries, plantar fasciitis. It is stated that excessive pronation and foot arch abnormality are the main reasons for plantar fasciitis [78–83], and yet the effect of rearfoot eversion on plantar fasciitis is less researched in runners [28,84].

There are many possible causes for rearfoot eversion or subtalar pronation, but no underlying etiological factor has been determined exactly so far. Compensatory overpronation may occur due to anatomical misalignments, such as a tibia vara greater than 10°, forefoot abduction/adduction, leg length discrepancy, ligamentous laxity, chronic ankle instability, or muscular weakness or tightness in the gastrocnemius and soleus muscles [85]. Subtalar pronation may be also influenced by external sources. Shoes significantly affect subtalar pronation [86–88]. Medial supports such as running orthotic devices are widely used in shoes to control compensatory rearfoot eversion [89–91]. Foot arch height is another factor closely linked with rearfoot eversion so that lower foot arch height is associated with greater rearfoot eversion [92]. Fatigue, which is attributed to prolonged running, may also affect both rearfoot eversion and foot arch height [53,93–95].

GAIT RETRAINING

Gait retraining is an increasingly common intervention to modify faulty biomechanical factors in order to prevent lower limb injuries. This training method is a way of inducing the body or a segment to change a movement pattern or a segment's motion direction during running. Gait retraining can also be a part of rehabilitation programs to treat running-related injuries. Thanks to the promising results of gait retraining as well as high compliance, gait retraining is considered the most successful method to reduce mechanical loading on the musculoskeletal system [96]. Step rate, step width, step length, and foot strike are the most common parameters retrained to modify biomechanical risk factors associated with RRIs [96–99].

Gait retraining can be implemented in various ways [96]. Running gait retraining using real-time visual feedback is a novel and effective strategy to change biomechanical parameters. Data related to tracking markers and/or force plates are processed into a target parameter in real time and projected on a screen. This allows runners to follow their running style in real time or change their running style based on a specific biomechanical task.

AIMS OF THIS THESIS

The overarching aim of this thesis is to investigate the risk factors for running-related injuries, with a special emphasis on kinematic risk factors. The following specific research aims will be addressed:

- To identify the risk factors associated with running-related injuries
- To systematically review and describe kinematic risk factors for lower limb tendinopathy in runners
- To design running gait retraining protocols for modifying rearfoot eversion
- To investigate the validity and reliability of a smartphone application for lower limb kinematics during running

OUTLINE OF THE THESIS

Chapter 2 describes the risk factors associated with running-related injuries. Using a questionnaire, this study investigates common running-related injuries, locations of injuries, and potential risk factors for running-related injuries. Chapter 3 describes a systematic review and meta-analysis of the kinematic risk factors for running-related lower limb tendinopathies in distance runners. Chapters 4 and 5 describe the running gait retraining protocols for modifying rearfoot eversion. Studies investigating the effect of changing foot progression angle (Chapter 4) and center of pressure (Chapter 5) using real-time feedback on rearfoot eversion in healthy female runners are reported. Because a 3D motion analysis system requires expensive equipment and a time-consuming set-up, which limits application of 3D motion analysis systems for lower limb kinematic analysis in the clinical setting and daily practice, Chapter 6 describes a study examining the validity and reliability of a smartphone application for measuring rearfoot eversion and sagittal plane lower limb kinematics during running. Chapter 7 finalizes the thesis with a discussion on the most important findings and limitations from these studies, and clinical implications and recommendations for future studies are discussed.

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